(a) TITLE: METHOD AND SYSTEM FOR CENTERING A WORKPIECE ON THE CENTRAL AXIS OF A CYLINDRICAL BORE

(b) CROSS-REFERENCES TO RELATED APPLICATIONS

(Not Applicable)

(c) STATEMENT REGARDING FEDERALLY-SPONSORED RESEARCH AND DEVELOPMENT

(Not Applicable)

(d) REFERENCE TO AN APPENDIX

(Not Applicable)

TECHNICAL FIELD

[0001] The present invention relates to the field of equipment positioning systems and, more particularly, to a method and system for precisely positioning a workpiece on the central axis of a cylindrical bore.

BACKGROUND OF THE INVENTION

[0002] Various industries that manufacture and assemble machinery having close tolerance, reciprocating parts have recognized the importance of having precise alignment among the reciprocating parts and the stationary components. The importance of such alignment may be explained using the widely applicable example of a piston reciprocating in a cylindrical bore. The simplest example is a piston that is free to reciprocate within the cylindrical bore with its path of reciprocation in the bore not restricted by anything except the bore. The movement of such a piston is guided by the surrounding walls of the cylindrical bore so there is no need for alignment.

[0003] However, if such a piston also has an axial hole through the center and slides on an axially aligned rod passing through the hole, the path of reciprocation is determined by both the walls of the cylindrical bore and the rod. Therefore, if the rod upon which the piston slides is sufficiently out of alignment with the central axis of the cylindrical bore, then at some point during the stroke of the piston where the rod is displaced radially from the central axis, the clearance, which should be a constant throughout the length of the stroke, will become nonexistent and excessive contact will occur. Such contact is often very damaging to the equipment and extremely difficult to repair, if not irreparable. Additionally, such contact will

often wear down the various components thereby reducing the efficiency of the machine or causing it to malfunction.

[0004] In the past, centering of such components was performed manually. Human errors, compounded with errors from manual measurement equipment, did not provide the level of precision that is required by today's tolerances. Additionally, such manual determinations are difficult and time consuming for even the most skilled machinist. Further, often the alignment needs to be performed to a greater accuracy than can be achieved by a purely mechanical device.

[0005] More recently, semi-automated centering devices have been developed but they generally include a multitude of gages, meters, and indicators that must be carefully attached to the bore and are often extremely sensitive. Further, it is often necessary for such gages, meters, and indicators to extend into the bore to perform their functions, making them difficult to use, adjust, and read. Advanced optical alignment systems do exist, however they often require precision optics to produce predetermined patterns of light and are often extremely sensitive and cost prohibitive.

[0006] Precise centering of reciprocating components within a cylindrical bore is a need often encountered in the field of free piston machines, particularly Stirling devices such as Stirling engines and coolers. The efficiency of such devices is dependent upon exacting tolerances between the stationary and reciprocating components. In fact, the radial clearance between such components is often 12 to 13 microns.

[0007] Free piston coolers operating with such close tolerances generally incorporate linear gas bearings as well as specially designed surface coatings, such as fluoropolymers, on the reciprocating components. The radial loading on the linear gas bearings is minimized by attempting to maintain a consistent clearance throughout the stroke of the reciprocating

components. In order to maintain a consistent clearance throughout the stroke of a free piston machine, the rod that passes through a hole in the piston along which the piston slides, such as the displacer rod, must be perfectly centered within the bore. When the displacer rod is not perfectly centered, the piston sidewalls approach the bore walls at some point during the stroke thereby getting closer than the desired clearance and increasing the radial bearing load. Only a slight misalignment of the displacer rod may result in contact between the piston and the bore. Therefore, misalignment of the displacer rod results in reduced bearing life as well as undue wear on the various components of a free piston machine.

[0008] Accordingly, there is a need for a precise centering method and system that is economical, portable, and easy for an unskilled operator to use. While some of the prior art devices attempted to improve the state of the art of centering systems, none have achieved the beneficial attributes of the present invention. With these capabilities taken into consideration, the instant invention addresses many of the shortcomings of the prior art and offers significant benefits heretofore unavailable.

SUMMARY OF INVENTION

[0009] This invention recognizes that numerous industries require the ability to accurately center a workpiece within a cylindrical bore such that the center of the workpiece is coaxial with the central axis of the cylindrical bore. This is particularly true in applications wherein the workpiece reciprocates within the cylindrical bore.

[0010] The present invention is directed to precisely centering a workpiece within a cylindrical bore such that the center of the workpiece is substantially coaxial with the central axis of the bore. The method first senses and calculates the location of the central axis of the bore and

then senses and calculates the position of the workpiece so that it can be aligned with the previously determined central axis. An arbor that precisely fits within the cylindrical bore is used in determining the location of the central axis. The arbor has a reference pin extending from one end that is centered on the arbor. It is the location of this reference pin that is sensed to determine the location of the central axis.

[0011] Once the central axis is determined, the arbor is removed from the cylindrical bore and the workpiece is inserted into the bore. The location of the workpiece is then sensed and the center of the workpiece is calculated. The center of the workpiece is compared to the location of the central axis and the location of the workpiece is adjusted until the center of the workpiece and the central axis are substantially coincident.

[0012] A computer system receives data representative of the location of the reference pin and the workpiece and calculates the center of each. These centers are referred to as the bore axis target and the rod target. The targets may be visually displayed on a computer display or they may merely be coordinates resident in the memory of the computer system. Regardless of the representation of the targets, they serve as an indication of the current position of the workpiece and the final desired position of the workpiece. An individual, or an automated system, may then assess the location information and adjust the location of the workpiece to obtain the desired location.

[0013] The position of the reference pin and the workpiece is found via a location determining system which may incorporate numerous position sensing technologies, including, but not limited to, electromechanical systems and optical systems. For example, a mechanical position transducer may be used to sense the locations and generate an electrical signal representative of the position data that is transmitted to the computer system. Alternatively, a

plurality of light transmitters and light receivers may be used to generate and transmit beams of light from each of a plurality of light transmitters across the central axis to cooperating light receivers. The reference pin or the workpiece interferes with the transmission of the beam of light from each light transmitter to the cooperating light receiver resulting in a shadow being cast upon the opposing light receiver. The location of these shadows on the light receivers provides an indication of the location of the reference pin and workpiece.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Without limiting the scope of the present invention as claimed below and referring now to the drawings and figures:

[0015] FIG. 1 is a partial cross section view, not to scale, of a body having a cylinder in accordance with the present invention;

[0016] FIG. 2 is a partial cross section view, not to scale, of the body and an arbor of the present invention;

[0017] FIG. 3 is a top plan view, not to scale, of the body and arbor along with a schematic of the location determining system and the computer system displaying the central axis of the cylinder in accordance with the present invention;

[0018] FIG. 4 is a partial cross section view, not to scale, of the body with a workpiece to be centered in accordance with the present invention;

[0019] FIG. 5 is a top plan view, not to scale, of the body and workpiece along with a schematic of the location determining system and the computer system displaying the central axis of the cylinder and the position of the workpiece in accordance with the present invention;

[0020] FIG. 6 is a partial cross section view, not to scale, of a free piston cryocooler showing the component being centered in accordance with the present invention;

[0021] FIG. 7A is a partial cross section view, not to scale, of the stationary components of the free piston cooler of Fig. 6 in a partially disassembled condition;

[0022] FIG. 7B is a partial cross section view, not to scale, of the reciprocating components of the free piston cooler of Fig. 6 in a partially disassembled condition;

[0023] FIG. 8 is a partial cross section view, not to scale, of a portion of the free piston cooler and arbor of the present invention;

[0024] FIG. 9 is a top plan view, not to scale, of a portion of the free piston cooler, arbor, and optical system of the present invention;

[0025] FIG. 10 is a partial cross section view, not to scale, of a portion of the free piston cooler and workpiece of the present invention;

[0026] FIG. 11 is a partial cross section view, not to scale, of a portion of the free piston cooler, workpiece, and optical system of the present invention, taken along section line 11-11 in FIG. 10;

[0027] FIG. 12 is an elevated perspective view, not to scale, of the free piston cooler, arbor, and optical system of the present invention;

[0028] FIG. 13 is an elevated perspective view, not to scale, of the free piston cooler, displacer, displacer rod, piston, displacer spring, and optical system of the present invention; and

[0029] FIG. 14 is an elevated perspective view, not to scale, of the free piston cooler with the displacer, displacer rod, piston, and displacer spring installed and ready for centering, and optical system of the present invention.

[0030] Also, in the various figures and drawings, the following reference symbols and letters are used to identify the various elements described herein below in connection with the several figures and illustrations: CX, LB, Md, Mp, and Q.

DETAILED DESCRIPTION OF THE INVENTION

[0031] The detailed description set forth below in connection with the drawings is intended merely as a description of the presently preferred embodiments of the invention, and is not intended to represent the only form in which the present invention may be constructed or utilized. The description sets forth the designs, functions, means, and methods of implementing the invention in connection with the illustrated embodiments. It is to be understood, however, that the same or equivalent functions and features may be accomplished by different embodiments that are also intended to be encompassed within the spirit and scope of the invention.

[0032] With reference generally now to FIG. 1 through FIG. 5 which illustrate the basic principles of the invention, in one of many preferable configurations, the method and system of the present invention are directed to precisely centering a workpiece **200**, having a rod **210**, on the central axis **CX** of a cylindrical bore **110** in a body **100**. The method includes two distinct steps; first, sensing the location of the central axis **CX** of the bore **110** and, secondly, sensing the position of the rod **210** and aligning the center of the rod **210** with the central axis **CX**.

[0033] In determining the location of the central axis **CX** of the bore **110**, an arbor **300** is inserted into the proximal end **114** of the bore **110**. The diameter of the arbor **300** is slightly less than the diameter of the bore **110** so that the cylindrical exterior surface **310** of the arbor **300** matingly slides within the cylindrical bore **100**, in contact with the bore interior surface **112**. The

arbor **300** has a symmetrical reference pin **320** protruding from an end of the arbor **300**. Precise machining of the cylindrical bore **100** and the arbor **300** ensure that the center of the reference pin **320** is coaxial with the central axis **CX** of the bore **110**. The bore **110** has a proximal end **114**, which is open during application of the present method, and a distal end **116**, which may be closed. Additionally, the bore **110** may have a diameter **118** that is constant from the proximal end **114** to the distal end **116**, or the bore **110** may have a number of sections of different diameter, as illustrated in FIG. 1, FIG. 2, and FIG. 4. As seen in FIG. 2, the method generally uses an arbor **300** and a reference pin **320** configured such that when the arbor **300** is inserted into the bore **110,** the reference pin **320** extends beyond the proximal end **114** of the bore **110** to simplify the sensing of the location of the reference pin **320**, however, this is not required. The reference pin **320** provides a reference surface on the arbor **300**.

[0034] Next, the position of the reference pin **320** in a plane transverse to the central axis **CX** is sensed and pin position data is transmitted to a computer system **400**. The position of the reference pin **320** is found via a location determining system **500**. The location determining system **500** may sense the location of the reference pin **320** in any number of ways including, but not limited to, electromechanically and optically.

[0035] For example, a mechanical position transducer may be used to sense the location of the reference pin **320** and generate an electrical signal representative of the pin position data that is transmitted to the computer system **400**. Such a mechanical position transducer is a contact-type transducer whereby sensors physically contact the reference pin **320** and the signal may be analog an AC or DC voltage or current (4-20 mA), or a digital data signal, for example.

[0036] Alternatively and preferably, the location determining system **500** may be an optical system. An optical location determining system **500** comprises apparatus for generating

and transmitting a beam of light from each of a plurality of light transmitters across the central axis **CX** to cooperating light receivers. The reference pin **320** or the rod **210**, as will be described later, interferes with the transmission of the beam of light from each light transmitter to the cooperating light receiver resulting in a shadow being cast upon the light receiver. The location of the shadow on the light receiver provides an indication of the location of the reference pin **320**. Generally, a plurality of light beams are transmitted from light transmitters to light receivers at a predetermined spacing on opposite sides of the cylindrical bore **110** to sense the location of the reference pin **320**. In one particular embodiment, a pair of cooperating light transmitters and light receivers, that are orthogonal to one another, are utilized to generate and transmit two light beams across the central axis. One specific embodiment of an optical location determining system **500** will be discussed in detail later herein with particular reference to optically centering the displacer rod of a free piston cooler. Further, any of a number of various types of light transmitters and light receivers may be used in the present invention. In one embodiment, light transmitters incorporating light emitting diodes to generate the beams of light and light receivers having charge coupled devices are used.

[0037] The computer system **400** receives the signals from the location determining system **500** and then computes the center of the reference pin **320** from the pin position data. The computer system **400** then represents the center of the reference pin **320**, in other words, the central axis **CX** of the bore **110** is displayed, as a bore axis target **414**, as illustrated on the computer display **410** of FIG. 3. The computer system **400** may represent the bore axis target **414** in any number of ways. For instance, the bore axis target **414** may be visually represented as cross-hairs, or a dot, on a computer display **410**. Alternatively, the bore axis target **414** may only exist as stored data, such as coordinates, in the memory of the computer system **400** or the

coordinates may be displayed numerically. While the computer system **400** is generally discussed and illustrated herein as a laptop computer, or traditional central processing unit, the computer system **400** may be virtually any processor platform, as only minimal computing power is required for this method. For example, the computer system **400** may be conveniently packaged in a portable programmable logic controller for ease of use on a production line.

[0038] The arbor **300** is then removed from the bore **110** and the workpiece **200** is inserted into the bore **100**, as illustrated in FIG. 4. The proximal end **212** of the workpiece rod **210** generally extends from the proximal end **114** of the bore **110**, although that is not necessary. The distal end **214** of the rod may generally rest on the distal end **116** of the bore **110** during application of this method to this particular embodiment. Next, the position of the rod **210** in a plane transverse to the central axis **CX** is sensed, preferably in the same manner as the arbor pin position was sensed, and the rod position data is transmitted to the computer system **400**. Of course it is not necessary to directly sense the rod itself if another reference surface is accurately positioned on the rod, such as a coaxial extension of the rod.

[0039] The computer system **400** then computes a center of the rod **210** from the rod position data and represents the rod center as a rod target **412**. As previously discussed with reference to the bore axis target **414**, the computer system **400** may represent the rod target **412** in any number of ways, such as those described above. For instance, the rod target **412** may be visually represented as cross-hairs, or a dot, on a computer display **410**. The computer display **410** of FIG. 5 illustrates both the previously determined bore axis target **414** and the rod target **412** on the same computer display **410**. The rod target **412** of FIG. 5 is not aligned with the bore axis target **414** and is therefore not on the central axis **CX**.

[0040] Lastly, the position of the rod **210** is adjusted to bring the rod target **412** substantially coincident with the bore axis target **414**, indicating that the rod **210** is aligned on the central axis **CX.** This step of adjusting the rod **210** position may be accomplished manually or it may be automated. In many applications the degree to which the rod **210** position needs to be adjusted is very small and requires finely calibrated equipment.

[0041] In embodiments where the bore axis target **414** and the rod target **412** are actually displayed on a computer display **410**, as seen in FIG. 5, an operator may visually identify the location of the rod **210** with respect to the position of the central axis **CX**, or bore axis target **414**, and adjust the location of the rod **210** accordingly until the rod target **412** and the bore axis target **414** are substantially coincident. Alternatively, embodiments wherein the rod target **412** and bore axis target **414** only exist as stored data in the memory of the computer system **400**, the computer software may incorporate and display vector instructions to an operator to substantially align the targets **412**, **414**, or the computer system **400** may instruct an automated positioning system to substantially align the targets **412**, **414**. As one with skill in the art will appreciate, the computer system **400** may incorporate audible signals to instruct the alignment or indicate how close the rod target **412** is to the bore axis target **414**.

[0042] Following alignment, some type of support or guide structure associated with the rod **210** is usually then tightened in position, as described below with respect to the preferred embodiment.

[0043] The method and apparatus of the invention have particular application in the field of free piston machines, particularly free piston Stirling cycle coolers and engines, where it is sometimes essential to have the center of a displacer rod coaxial with the central axis of a cylinder. While the shapes of the cylindrical bore **110** and the workpiece **200** in FIG. 1 through

FIG. 5 are similar to those of a free piston, Stirling cycle machine, application of the current method to a free piston cooler **700** is illustrated in detail in FIG. 6 through FIG. 14, and is described below.

[0044] With reference now to FIG. 6, FIG. 7A, and FIG. 7B, the free piston cooler **700** has a cold head **710** and a warm end **720**. The free piston cooler **700** includes a piston **730**, driven by a piston driver **732**, reciprocating partially within a cylinder **750**, and a displacer **740** having a displacer rod **742**, passing through an inner bore of the piston **730**, attached to a displacer spring **744** by a connector **746**, all enclosed in a housing **770**. The piston driver **732** is a linear motor having an armature winding **733** which drives magnets **734** that are fixed to the piston **730**, as seen in FIG. 7B. The displacer spring **744** that is illustrated is a planar spring like that shown in U.S. Patent 5,525,845. The housing **770** is removed in FIG. 7A and FIG. 7B and the components of the free piston cooler **700** that reciprocate are shown in FIG. 7B, while the stationary components are illustrated in FIG. 7A. The displacer **740** reciprocates within the lower portion of the cylinder **750**, indicated by motion indicator **Md** in FIG. 7B, between the cold head **710** and the warm end **720**, and the piston **730** reciprocates within the upper portion of the cylinder **750** on the displacer rod **742** and bounded by the cylinder **750**.

[0045] During operation of the free piston cooler **700**, the piston driver **732**, typically an electric linear motor, moves the piston **730** in the directions of motion indicated by **Mp** in FIG. 7B. The movement of the piston **730** from a first position to a second position, where the direction of travel reverses, defines a stroke, also referred to as amplitude. In operation, a working fluid, generally helium, is transported, compressed, and expanded by the combined movement of the piston **730** and the displacer **740**. As previously mentioned, the movement of the piston **730** is effected by the piston driver **732**.

[0046] The motion of the displacer **740** is the result of many combined actions including, but not limited to, changes in the working fluid pressure created by the movement of the piston **730**, energy storing spring effects in the free piston cooler **700** introduced by the displacer spring **744**, changing properties of the working fluid, and other internal displacer control devices. The movement of the displacer **740**, indicated by **Md**, shuttles the working fluid between the cold head **710** and the warm end **720**, generally through a working fluid passage **760** having a regenerator **762**, illustrated in FIG. 7A.

[0047] The regenerator **762** consists of an energy storage medium to and from which the working fluid may transfer energy as it cycles from the cold head **710** to the warm end **720**, and back again. Modern regenerators **762** may incorporate pieces of fine porous metal between the cold head **710** and the warm end **720** to prevent unnecessary heat loss and improve efficiency. Heat, indicated by **Q**, is absorbed at the cold head **710** during expansion of the working fluid and heat **Q** is rejected at the warm end **720** during compression of the working fluid. Heat exchangers are generally attached to the cold head **710** and the warm end **720** to improve the transfer of thermal energy to, and away from, the free piston cooler **700**.

[0048] The piston **730** in the free piston cooler **700** reciprocates within and is bounded by the cylinder **750**. The piston **730** is suspended away from the cylinder walls with a gas bearing system. Peak efficiency is achieved in part by ensuring an extremely close fit, such as 12-13 microns radial clearance between the piston **730** and the cylinder **750**. The displacer rod **742** reciprocates within and is bounded by the inner bore of the piston **730**. The reciprocating motion between the piston **730** and the displacer rod **742** is out of phase and of different stroke lengths, resulting in a relative motion between the two parts. There is no gas bearing system that will suspend the displacer rod **742** away from the inner bore of the piston **730**, therefore, near perfect

alignment between the center of the cylinder **750** and the displacer rod **742** is desired so that the displacer rod does not contact the inner bore of the piston **730**. Contact between the displacer rod **742** and the inner bore of the piston **730** will cause wear on the displacer rod **742** surface and severe contact pressure can overcome the piston **730** gas bearing causing the piston **730** surface to contact the cylinder **730** surface which can cause undesired wear and possible free piston cooler **700** failure. Therefore, one application of the present invention is to align the displacer rod **742** of a free piston cooler **700** with the central axis **CX** of the cylinder to avoid wear of the interfacing, sliding surfaces.

[0049] Application of the present method to the free piston cooler **700** begins with the insertion of the arbor **300** into the cylinder **750**, as illustrated in FIG. 8 and FIG. 12. Next, at least one light beam **LB** is generated and transmitted, by the optical location determining system **510**, across the central axis **CX**. Generally, the casing **780** is formed with holes through which the light beam **LB** can pass. Further, the optical location determining system **510** is configured so as to conveniently clamp onto the casing **780** with at least one clamping device **800**, shown in FIG. 12. This is better illustrated in the top plan view of FIG. 9. In the embodiment of FIG. 12, four clamping devices **800** secure the optical location determining system **510** to the casing **780** and take the form of large knurled screws **800**.

[0050] Two light transmitters **520**, **530** generate and transmit beams of light **524**, **534** across the reference pin **320** of the arbor **300**. As the reference pin **320** interferes with the first light beam **524** a first light beam shadow **526** is created and cast upon the first light receiver **522**. Similarly, as the reference pin **320** interferes with the second light beam **534** a second light beam shadow **536** is created and cast upon the second light receiver **532**. One exemplary embodiment incorporates an off-the-shelf optical location determining system **510**, namely a Keyence optical

positioning system. In this embodiment, the light transmitters **520**, **530** are Keyence LS 7030T transmitters and the light receivers **522**, **532** are Keyence LS 7030R receivers.

[0051] In this particular embodiment the first light beam **524** and the second light beam **534** are orthogonal to each other, however this is not required. Virtually any predetermined relationship between the light beams **524**, **534** may work with this method. Similarly, while is it most convenient to utilize a symmetrical reference pin **320**, it is not a requirement provided that the position of the reference pin **320** and the light beams **524**, **534** are carefully positioned to a predetermined relationship. Any asymmetry needs to be accounted for in the software, specifically in the mathematical computations made by the computer. Likewise, one with skill in the art will appreciate that the present method will work equally as well with workpiece rods **210** that are noncircular, or even asymmetric, provided predetermined relationships are established and accounted for in the software.

[0052] The light receivers **522**, **532** then transmit pin position data, determined from the locations of the shadows **526**, **536**, to the computer system **400**. The computer system **400** then computes the center of the reference pin **320** and represents the center as the bore axis target **414**, seen previously in FIG. 3, which is also the location of the central axis **CX**.

[0053] Next, the arbor **300** is removed from the cylinder **750** and the reciprocating components, namely the displacer **740**, the displacer rod **742**, the piston **730**, and the displacer spring **744** are positioned as illustrated in FIG. 10, FIG. 13, and FIG. 14. Conveniently, the gas bearing system of the displacer **740** effectively centers the lower portion of the displacer rod **742** in the cylinder **750** during cooler operation, thereby only requiring accurate positioning of the end of the displacer rod **742** nearest the displacer spring **744**. Again, at least one light beam **LB** is generated and transmitted across the central axis **CX**. This is better illustrated in the top plan

view of FIG. 11. Here, the two light transmitters **520**, **530** now generate and transmit beams of light **524**, **534** across the displacer rod **742**. As displacer rod **742** interferes with the first light beam **524** a first light beam shadow **526** is created and cast upon the first light receiver **522**. Similarly, as the displacer rod **742** interferes with the second light beam **534** a second light beam shadow **536** is created and cast upon the second light receiver **532**. Since the edges of the shadow are detected by light receivers, the position of the center of the each shadow can be computed to provide two-dimensional, numerical coordinate position data in both the x and y axes. These numerical coordinates represent the position of the center line of the cylinder so long as the optical system is not moved during the subsequent process of removing the arbor and inserting the displacer and piston.

[0054] The light receivers **522**, **532** transmit rod position data, determined from the locations of the shadows **526**, **536**, to the computer system **400**. The computer system **400** then computes the center of the displacer rod **742** and represents the center as the rod target **412**, as previously seen in FIG. 5. As previously disclosed, the displacer rod **742** may now be manually, or automatically, repositioned until the rod target **412** is substantially coincident with the bore axis target **414**. The embodiment of FIG. 12, FIG. 13, and FIG. 14 illustrates a plurality of adjustment devices **810**, namely precision calipers, used to position the displacer spring **744** so that the displacer rod **742** is substantially centered within the cylinder **750**. Once the proper position is located, the displacer spring **744** is attached to the casing **780** to fix the location of the displacer rod **742**.

[0055] It is important that the location determining system be rigidly fixed to the body in which the cylindrical bore is formed. Any movement of the location determining system with respect to the body during performance of the alignment will generate erroneous position data.

Therefore, it is desirable to incorporate a sensing system to detect such motion, input its data to the computer and that the computer software be written to monitor the sensing system and display or sound a warning that movement has occurred and the alignment results are erroneous. The preferred way of accomplishing this is to sense the position of the four holes through the casing through which the light beams are transmitted. These holes are arranged in two orthogonally aligned opposite pairs of holes through the casing. Two such holes **782** and **784** are visible in Figs. 12 and 13. Light transmitters are used which transmit a light beam that is wider than the holes through the casing so that the light falling upon the light receivers has outer boundaries representing the shadow cast by the casing at the edges of the holes in the outer casing and an inner shadow representing the arbor pin or the displacer rod. This creates two spaced light beams falling upon the light receivers. The innermost boundaries of those light beams represent the outer edges of the arbor pin or the displacer rod and the outermost boundaries represent the edges of the holes. These edges provide data representing the location of the hole edges and that data is also transmitted to the computer. The computer then monitors the position of those hole edges and, if they move during the alignment process, the computer then signals that such motion has occurred and therefore the alignment may be in error.

[0056] While the description of the free piston cooler embodiment is directed toward an optical location determining system, one with skill in the art will appreciate that the previously disclosed electromechanical determining system may be just as easily applied.

[0057] Numerous alterations, modifications, and variations of the preferred embodiments disclosed herein will be apparent to those skilled in the art and they are all anticipated and contemplated to be within the spirit and scope of the instant invention. For example, although specific embodiments have been described in detail, those with skill in the art will understand

that the preceding embodiments and variations can be modified to incorporate various types of substitute and or additional or alternative materials, relative arrangement of elements, and dimensional configurations. Accordingly, even though only few variations of the present invention are described herein, it is to be understood that the practice of such additional modifications and variations and the equivalents thereof, are within the spirit and scope of the invention as defined in the following claims.